Hybridization of the Dual-Grid FDTD with the Physical Optics to Analyze Antennas Mounted on Large and Complex Platforms

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B. Le Lepvrier* R. Loison† R. Gillard‡ L. Patier§ P. Potier¶ P. Pouliguen‖

Abstract — **This paper presents a new simulation strategy based on the hybridization of a full wave time domain multi-scale method, the Dual-Grid FDTD (DG-FDTD), and the Physical Optics (PO). This new method aims at simulating antennas mounted on large conducting platforms and whose nearby surrounding environment is very complex. Typical application fields of the hybrid DG-FDTD/PO method are the computation of radiation patterns of antennas mounted on carriers such as satellites, ships, aircraft and land vehicules.**

1 INTRODUCTION

The increasing of telecommunication systems requirements for modern land vehicules, aircrafts and satellites implies a growing number of electronic radiating systems on board. Due to the limitation of available physical space, antennas must be mounted close to complex environment. It results in strong electromagnetic interactions between the antenna and the platform. Therefore, it becomes of great importance to have appropriate tools to quantify the distorsion of on-board antennas parameters.

The problem described above is very challenging for at least three reasons. First of all, the analysis of an antenna mounted on a platform requires to simulate an electrically large structure taking into account very small details compared to the wavelength (geometrical details of the antenna for example). These multi-scale problems are by nature very consuming in terms of computing ressources. Secondly, as already said above, the nearby surrounding environnement of the antennas tends to be more and more complex and close to the antenna. This makes necessary to analyse this domain rigorously in order to correctly take into account the strong near field interactions. The third aspect is related to the wide frequency band over which the antennas have to be analysed nowadays. This is mainly due to the evolution of the applications toward increased bandwith and frequency reconfigurability.

One possible way to simulate antennas on structure without requiring massive computing ressources is to use hybrid methods. They associate a traditional full wave method and an asymptotic one. This approach has been extensively followed over the last decades. Several examples of hybrid methods working in the frequency domain can be found in the litterature [1, 2]. Time domain hybrid methods have also been developped in order to solve large band problems [3, 4]. However, these methods do not provide a satisfactory answer for the computation of modern problems of antennas on platforms. The main limitation deals with the computation of the complex nearby surrounding environment of the antenna. It is both too complex to be solved with the asymptotic method and too large to be computed efficiently with the full wave method.

In this article we present a new computational method well suited to the computation of modern problems of antennas on platform. This method is based on the hybridization of the Dual-Grid FDTD (DG-FDTD) [5] and the frequency-domain Physical Optics (PO). The DG-FDTD method has been proved to be well suited to analyse rigorously and efficiently antennas and their complex nearby surrounding environment over a wide band of frequency [6]. The hybridization of the DG-FDTD with the PO allows to extend the range of application of the full wave multi-scale method in order to compute the radiation of antennas mounted on electrically very large structures.

This paper is organised as follows. In section 2,

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the principle of the hybrid DG-FDTD/PO method is presented. In section 3, the DG-FDTD/PO is validated using a monopole mounted on a canonical structure. The accuracy and performance of the new approach are demonstrated by comparison with complete full wave simulations of the problem.

2 DG-FDTD/PO PRINCIPLE

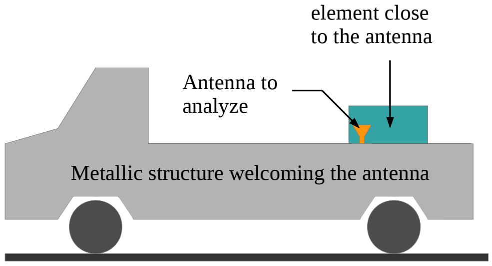

Figure 1: Antenna mounted on a vehicule.

In order to illustrate the principle of the DG-FDTD/PO hybrid method, a basic antenna on platform problem is considered (Figure 1). In this problem, an antenna with a nearby surrounding environment is mounted on a vehicule. The approach is based on the decomposition of the initial electromagnetic problem into two simulations. First, the DG-FDTD is used to compute rigorously and efficiently the antenna and its nearby surrounding environment. Then, a PO simulation of the metallic structure hosting the antenna is performed. These two DG-FDTD/PO steps are presented in Figure 2.

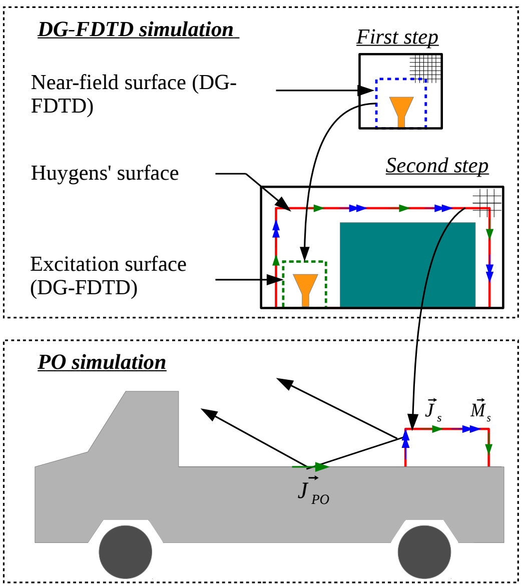

Figure 2: DG-FDTD/PO principle.

2.1 DG-FDTD simulation

The DG-FDTD simulation of the antenna and its nearby surrounding environment is divided into two successive FDTD simulations [5]. The first step aims at accurately characterizing the antenna alone. Therefore a very fine FDTD mesh is used during this simulation. The near field radiated by the antenna is stored during this step by the means of a near-field surface placed around it. In the second step, the antenna and its nearby surrounding environment are described using a coarser FDTD mesh. The near field stored in the previous step is used as the excitation. During this FDTD simulation, the tangential fields over a closed Huygens' surface including the antenna and its nearby surrounding environment are recorded. This surface later plays the role of interface between the DG-FDTD simulation and the PO one.

2.2 PO simulation

The PO simulation starts by calculating, in the frequency domain, the equivalent surface currents $\vec{J_s}$ and $\vec{M_s}$ over the Huygens' surface. The tangential fields coming from the coarse FDTD simulation are used to calculate these currents. Then, equivalent currents are used in near field Kirchoff approximation to compute the incident magnetic field over the metallic structure. The induced currents $\vec{J_{PO}}$ are then calculated thanks to the traditional PO approximation. Finally, the last step consists in adding up the fields radiated respectively by the equivalent currents $\vec{J_s}$ and $\vec{M_s}$ of the Huygens' surface and the induced currents $\vec{J_{PO}}$ on the structure.

To conclude, the proposed method allows to compute the radiation pattern of an antenna mounted on an electrically large metallic structure rigorously taking into account its complex nearby surrounding environment.

3 VALIDATION OF THE DG-FDTD/PO METHOD

3.1 Description of the scenario

The DG-FDTD/PO approach is validated considering the radiation of a monopole antenna mounted on an electrically large canonical structure (Figure. 3). More precisely, a monopole whose central frequency is 1 GHz is placed at the center of a ground plane. This ground plane is loaded by a vertical metallic plate in order to form a dihedral structure. Finally, a lossless dielectric cube is placed close to the antenna.

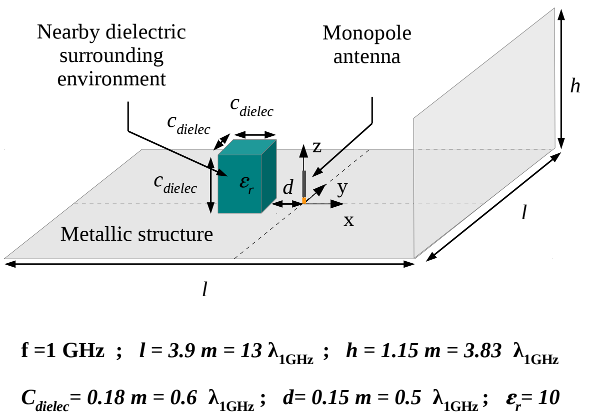

Figure 3: Canonical scenario used for the validation.

3.2 DG-FDTD/PO decomposition of the E.M. problem

The overall problem is splitted into two successive simulations. First, the DG-FDTD is used to simulate the monopole with the dielectric cube. This DG-FDTD simulation is done in two steps. The monopole lying on an infinite ground plane is first simulating in a FDTD volume with a fine description ($\lambda_{1GHz}/60$ mesh). Then, the antenna is simulated taking into account the dielectric material. A coarser FDTD mesh ($\lambda_{1GHz}/30$ mesh) is used to model the elements. In this simulation it is still assumed that the antenna and its nearby surrounding environment lie on an infinite ground plane. Once the DG-FDTD simulation is finished, a PO simulation of the metallic structure is performed. A coarse $\lambda_{1GHz}/6$ mesh is used to model the structure hosting the antenna. It can be noted that the antenna and its nearby surrounding environment are replaced by a flat metallic plate in this simulation.

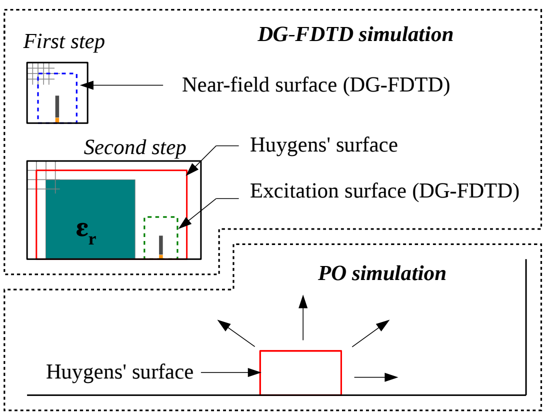

Figure 4: DG-FDTD/PO decomposition of the electromagnetic problem.

3.3 Reference simulations

The overall validation test case is also computed with two full wave methods : the FDTD method and the Method of Moment (MoM). By doing those simulations, we intend to get reference results for the validation of the new hybrid method. In order to increase the reliability of the validation, we choose one time-domain volume method (FDTD) and one frequency-domain surface method (MoM).

The FDTD code used to simulate the entire validation case is an in house code which does not set up parallel calculation. The scenario has been meshed with cubic elements of $\lambda_{1GHz}/30$ side length. MoM simulation has been performed with FEKO [7] software using a $\lambda_{1GHz}/16$ mesh. Moreover, parallel computation and Multi Level Fast Multipole Method (MLFMM) algorithm have been used to speed up the computation.

It must be noted that the dimensions of the validation test case have been choosen in order to compute the overall problem with the full wave methods in a reasonable time.

3.4 Numerical results

Figures 5 and 6 show the normalised E_θ far-field radiation pattern in the (x0z) and (y0z) planes computed with the DG-FDTD/PO and the two reference methods. We can observe that the results obtained with the hybrid DG-FDTD/PO method are in very good agreement with those coming from the full wave methods. These results tend to demonstrate that the DG-FDTD/PO approach allows to analyse antenna on platform problems with a very good accuracy even if strong near-field antenna/structure interactions are involved.

Figures 5 and 6 also present the radiation pattern of the antenna with its nearby surrounding environment without taking into account the contribution of the structure (antenna and dielectric block on an infinite ground plane). It corresponds to the diagrams obtained after the second step of the DG-FDTD. Results clearly show the necessity to take into account the overall antenna environment of integration.

3.5 Computation time

The computation time associated with each simulation is reported in Table 1. Those simulations have been carried out on a six core Intel Xeon machine (2.4 GHz) with 48 Gb RAM. FEKO results assume calculation have been distributed over the six cores. We also recall that DG-FDTD and DG-FDTD/PO code have not been parallelized.

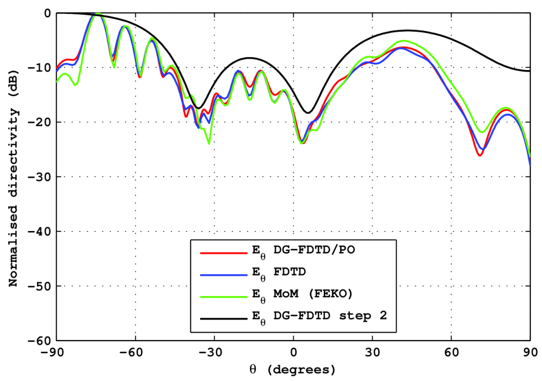

Figure 5: Far-fiel E_θ in the (x0z) plane at 1GHz.

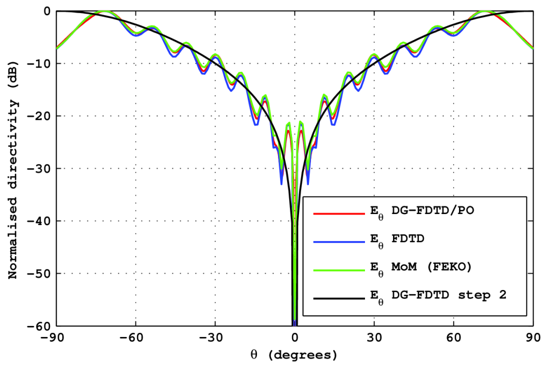

Figure 6: Far-fiel E_θ in the (y0z) plane at 1GHz.

First, we can see that hybrid DG-FDTD/PO method allows to reduce significantly the computation time compared to a full wave FDTD simulation. The FDTD method is penalised here by its volumetric meshing. Then, DG-FDTD/PO code turns out to be faster than FEKO software for the computation of 11 frequency points taken on the [0.8;1]GHz band. The new hybrid method takes advantage of the wide band caracteristic of the DG-FDTD and the fastness of the PO computation.

4 CONCLUSION

A new hybrid method associating DG-FDTD and frequency-domain PO has been proposed. This method called DG-FDTD/PO allows fast and reliable computations of wide band antennas with a very close surrounding environment and mounted on large metallic platforms. The method has been validated by comparison with two different full wave methods (FDTD and MoM).

frequency	1 GHz	[0.8;1] GHz 11 points
FDTD	43h 20min	43h 21min
MoM (FEKO)	6min	1h 07min
DG-FDTD/PO	13min 42s	20min 42s

Table 1: Computation time for the validation test case.

Acknowledgments

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